

# SEA LEVEL VARIATIONS ALONG PAKISTAN COAST

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## INTRODUCTION

1. Global warming is the rise in average temperature of Earth's atmosphere and oceans since the late 19<sup>th</sup> century and its projected continuation. Since the early 20<sup>th</sup> century, Earth's mean surface temperature has increased by about 0.8° C (1.4° F), with about two-thirds of the increase occurring since 1980. Warming of the climate system is unequivocal, and scientists are more than 90% certain that it is primarily caused by increasing concentrations of greenhouse gases produced by human activities such as the burning of fossil fuels and deforestation. These findings are recognized by the national science academies of all major industrialized nations.

2. Phenomenon of global land-ocean temperature rise is evident in Figure-1. Line plot of global mean land-ocean temperature index, 1880 to 2012, with the base period 1951-1980 is depicted graphically. The black line is the annual mean and the red line is the 5 years running mean. The green bars show uncertainty estimates. The graph shows an overall long-term warming trend. In the 1890s, the global temperature anomaly was on average slightly below -0.3 °C, with an error range of roughly -0.2 and -0.4 °C. In the 1940s, the global temperature anomaly was on average slightly below +0.1 °C, with an error range of roughly 0.0 and +0.15 °C. In the 2000s, the global temperature anomaly was on average slightly below +0.6 °C, with an error range of roughly +0.6 and +0.5 °C.

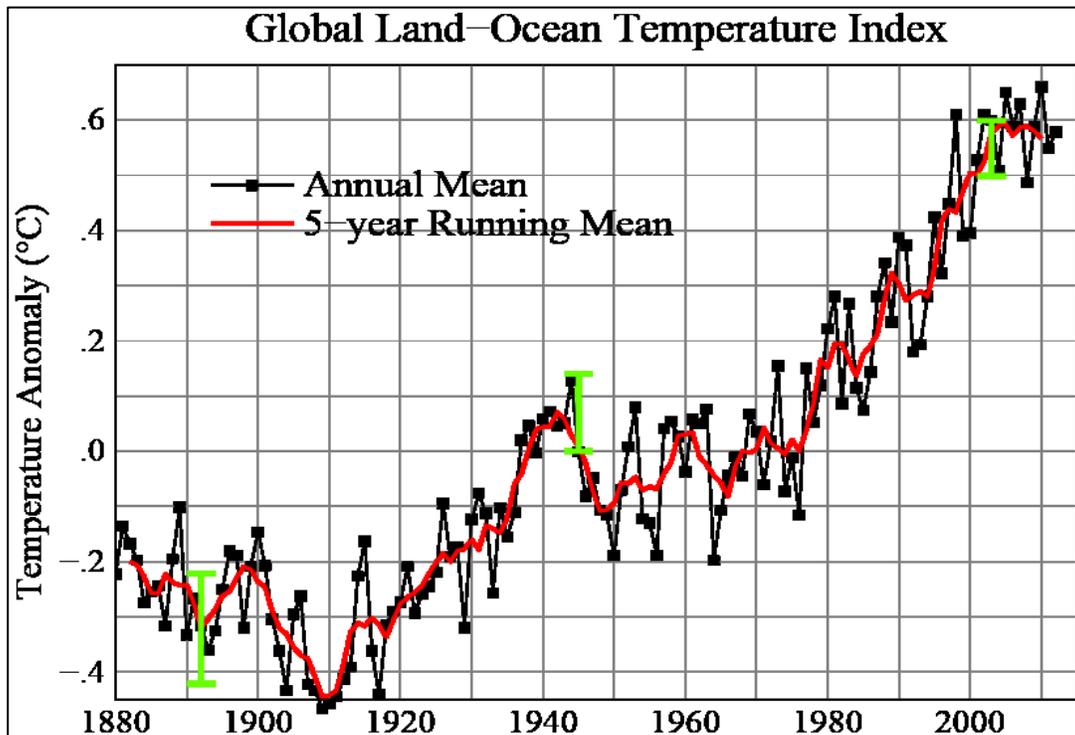


Figure – 1  
Global mean land-ocean temperature index from 1880 to 2012

## GLOBAL SEA LEVEL TREND AND TEMPERATURE VARIATIONS

3. Sea levels around the world are rising. Current sea-level rise potentially affects human populations (e.g., those living in coastal regions and on islands) and the natural environment (e.g., marine ecosystems). As highlighted in Figure-2, between 1870 and 2004, global average sea levels rose 195mm (7.7 in). From 1950 to 2009, measurements show an average annual rise in sea level of  $1.7 \pm 0.3$  mm per year, with satellite data showing a rise of  $3.3 \pm 0.4$  mm per year from 1993 to 2009, a faster rate of increase than previously estimated. It is unclear whether the increased rate reflects an increase in the underlying long-term trend.

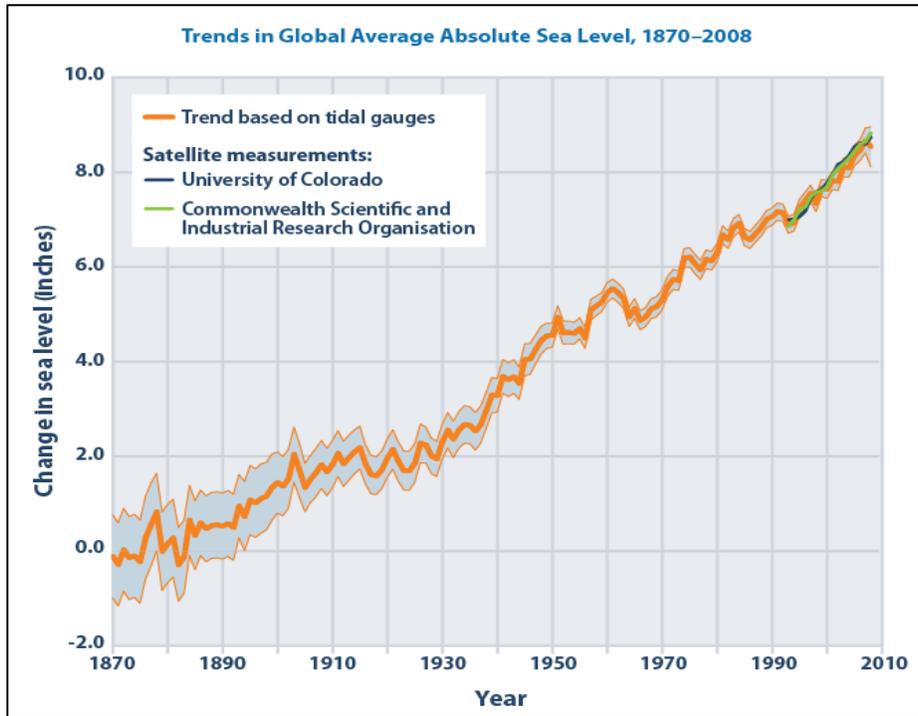


Figure – 2  
Global average sea levels rise from 1870 to 2004

4. Figure-2 indicates trends in global average absolute sea level between 1870 and 2008. As per US Environmental Protection Agency (US EPA) statement in 2010, after a period of approximately 2,000 years of little change, average sea levels rose worldwide throughout the 20<sup>th</sup> century, and the rate of change has accelerated in recent decades. When averaged over all the world's oceans, absolute sea level increased at an average rate of 0.06 inches per year from 1870 to 2008. From 1993 to 2008; however, average sea level rose at a rate of 0.11 to 0.13 inches per year—roughly twice as fast as the long-term trend as shown in Figure-2.

5. Instrumental record of global average temperatures as compiled by the NASA's Goddard Institute for Space Studies is shown in Figure-3. The zero on this figure is the mean temperature from 1961-1990. This figure was originally prepared from publicly available data and is incorporated into the Global Warming project. Blue colour indicates annually averaged data and red colour shows trend of 5 years average data.

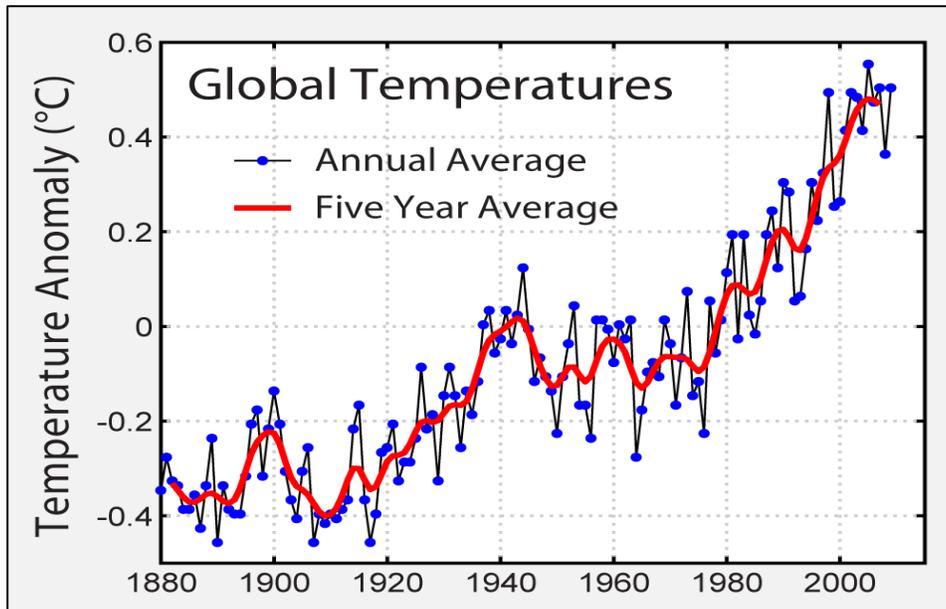


Figure-3  
Instrumental record of global average temperatures from 1880 to 2010

6. Changes in annually averaged sea level at 23 geologically stable tide gauge sites with long-term records as selected by Douglas (1997) is indicated in Figure-4. The thick dark line is a three-year moving average of the instrumental records. This data indicates a sea level rise of ~27.5 cm from 1800-2000.

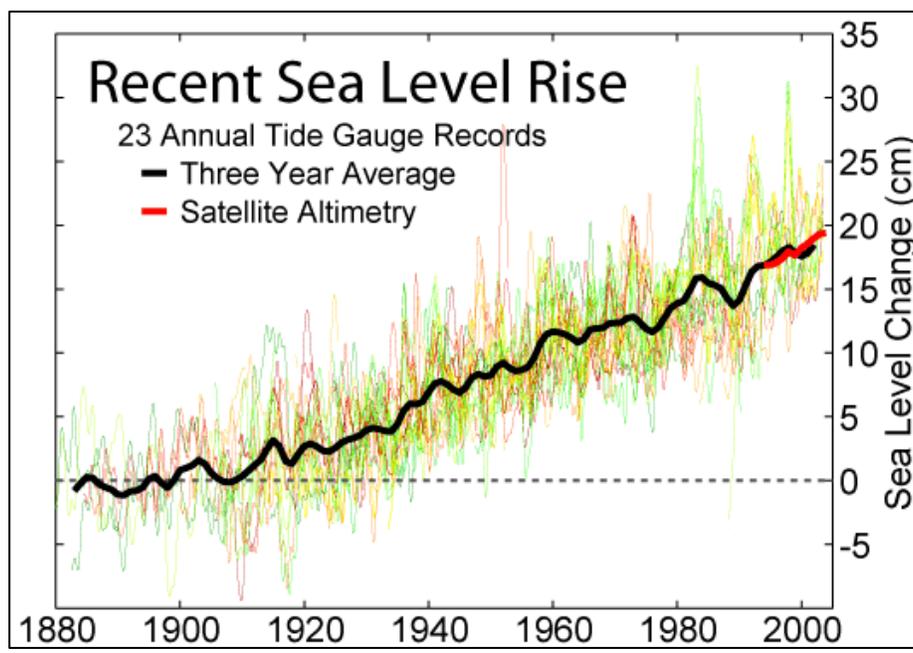


Figure-4  
Change in annually averaged sea level from 1880 to 2000

## **FUTURE FORCAST OF RISE IN TEMPERATURE AND SEA LEVEL**

7. Global estimates forecast a temperature increase of 1.4 – 5.8 °C with a corresponding rise in the sea level by 0.09 – 8.8m over a period of 1990 – 2100 (IPCC, 2001). Rise in the sea level caused by climate change would directly threaten low lying coastal areas and small Island states (UNEP, 1990). Studies using tide gauge data from Permanent Service for Mean Sea Level (PSMSL), have obtained rates of global SLR during last 100 years that range between 0.3 and 3.0 mm/ year, with most values concentrated between 1 and 2 mm/year (Pirazzoli, 1993). Since most values are concentrated between 1-2 mm/ year; therefore, this range may be treated as eustatic sea level rise (Hicks and Crosby, 1974).

## **LOCATION OF PAKISTAN IN GLOBAL TECTONIC NETWORK**

8. Geography of Pakistan is blend of landscapes varying from plains to deserts, forests, hills, and plateaus ranging from the coastal areas of the Arabian Sea in the south to the mountains of the Karakoram range in the north.

9. Pakistan geologically overlaps both with the Indian and the Eurasian tectonic plates where its Sindh and Punjab provinces lie on the north-western corner of the Indian plate. While Balochistan and most of the Khyber-Pakhtunkhwa lie within the Eurasian plate as shown in Figure-5. The Northern Areas and Azad Kashmir lie mainly in Central Asia along the edge of the Indian plate and hence are prone to violent earthquakes where the two tectonic plates collide.

10. Pakistan is bordered by Afghanistan to the north-west and Iran to the west while the People's Republic of China borders the country in the north and India to the east.

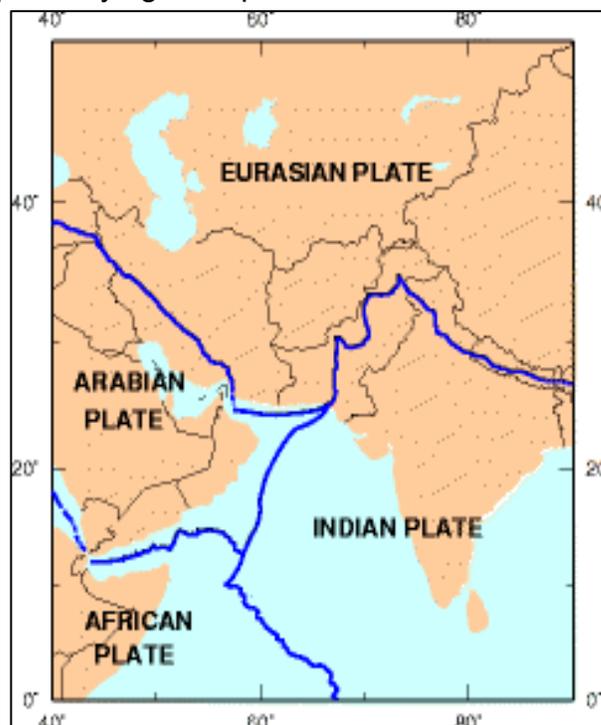


Figure-5  
Pakistan in Global tectonic network

## **OFF SHORE AREA**

11. Pakistan coast is 990 Km long extending from Indian border in the east to the Iranian border in the west. The Exclusive Economic Zone (EEZ) of Pakistan is about 240,000 Sq Km, with additional potential extension of continental shelf area of about 50,000 Sq Km. As such, the total maritime zone of Pakistan is over 30% of the land area. Maritime jurisdictions of Pakistan are as under:

- a. Territorial Sea: 12 NMs
- b. Contiguous Zone: 24 NMs

- c. Exclusive Economic Zone: 200 NMs
- d. Continental Shelf: 200 NMs (Extension to 350 NMs in process with UNCLCS)

12. Maritime region of Pakistan is characterized by distinctive oceanic phenomena, that produces rich fisheries, mineral, and hydrocarbon resource. The important oceanic phenomena and features are Monsoon and climatic change, upwelling and circulation, mixing of Red Sea and Gulf water, Indus estuary and sedimentation, submarine Indus Cone, Murray Fracture Zone (Leaky Transform Fault) and Makran subduction Margin. The area has a high potential of marine resources both non-living and living with an urgent need to understand the various physico-chemical, geological and biological processes operative in the area for optimum management and exploitation at a sustainable developments. Extensive survey, data collection and researches are required to understand the above processes and features which have direct bearing on locating the living and nonliving resources and their sustainable exploitation, protection and conservation.

**PAKISTAN COASTLINE**

13. Pakistan coastline of 990 Km is generally divided into two main sections on the basis of its physiographical characteristics; the Sindh coast and the Balochistan coast. The Sindh coast is about 320 km long with continental shelf deep stretches into the ocean and located in the south-eastern part of the country between the Indian border along Sir Creek on the east, while the Balochistan coast is 670 km long with steep and narrow continental shelf at south-western part of the country and borders with Iran near Jiwani in the west. The area Pakistan coastline is shown in Figure-6.

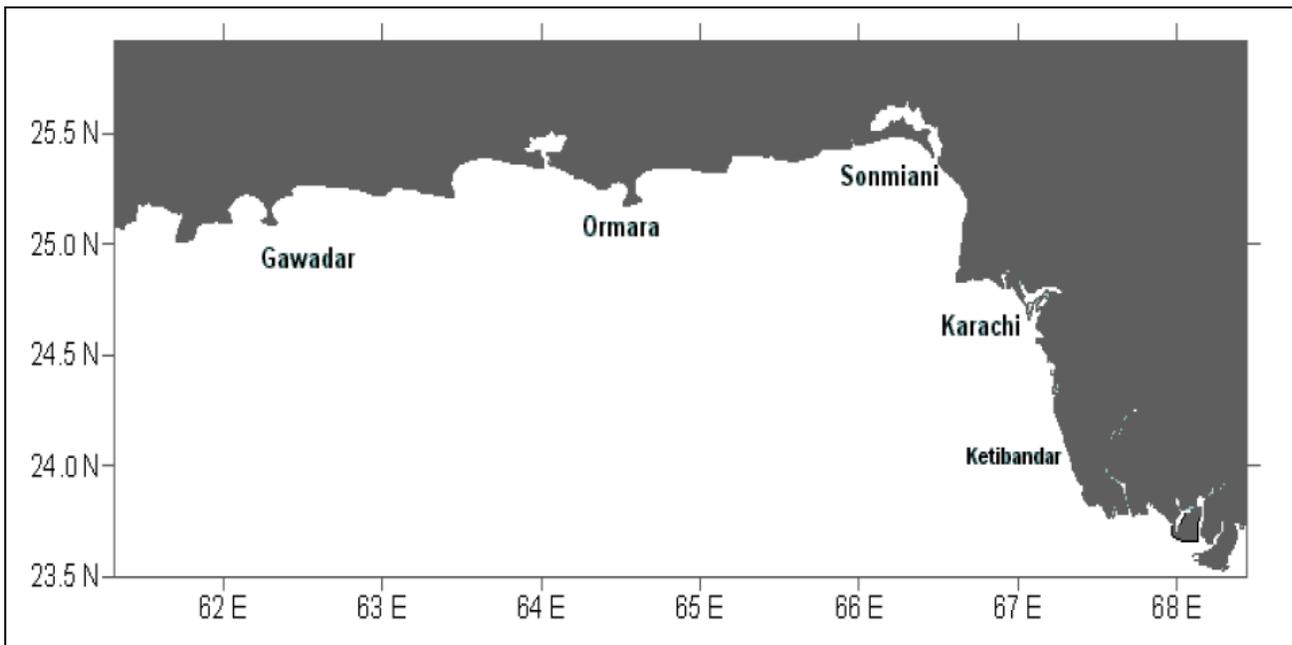


Figure-6  
Pakistan coastline

## VARIATION OF SEA LEVEL ALONG PAKISTAN COAST

14. Renowned scientists and scholars from Pakistan in a well researched publication (2002) titled 'Sea Level Variations and Geomorphologic Changes in the Coastal Belt of Pakistan' mentioned that the UNEP in its regional seas program in 1989 has included Pakistan in a group of countries which are vulnerable to the impact of rising sea level. According to the publication, if the present trend of sea level rise (SLR) at Karachi continues, in the next 50 years the sea level rise along the Pakistan Coast will be 50 mm (5 cm). Research has concluded that the rising rate of sea level at Karachi is within the global range of 1-2 mm/year; therefore, the trend may be treated as eustatic SLR.

15. Sea level changes are affected by complex combination of local, regional and global processes. Sea Surface Temperature (SST) is one of the most important climate parameter affecting sea level variation. Historical air temperature and SST data of Karachi also shows an increasing pattern. An increasing trend of about  $0.67^{\circ}\text{C}$  has been registered in the air temperature over the last 35 years, whereas the mean SST in the coastal waters of Karachi has also registered an increasing trend of about  $0.3^{\circ}\text{C}$  in a decade.

### Annual Mean SST

16. The inter-annual variation and linear trend analysis on the Satellite derived SST data observed near the 5 coastal stations of Pakistan is shown in Figure-7. The trend analysis of annual mean SST indicates temporal oscillations of 2-3 years and 5-6 years.

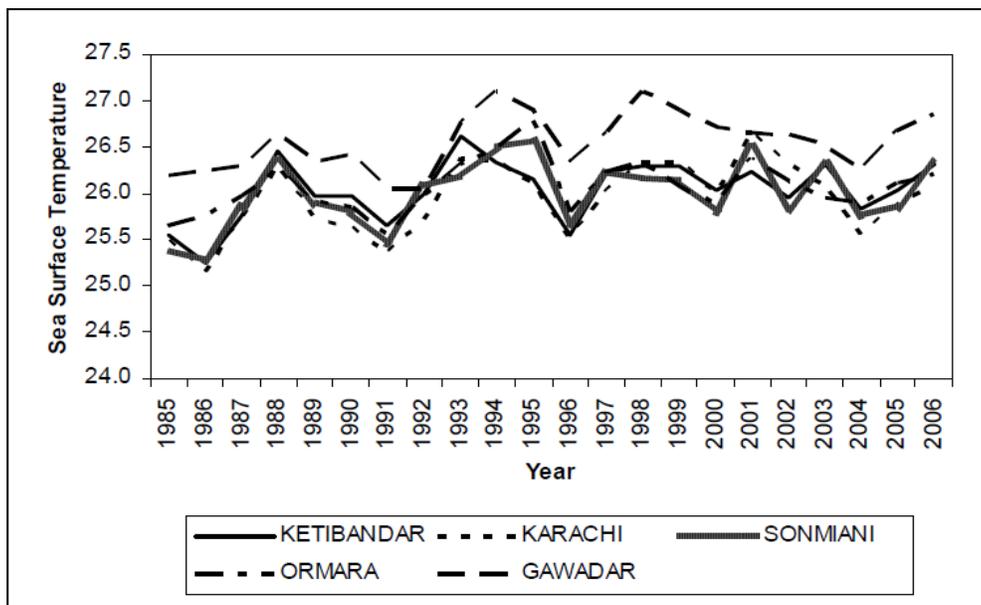


Figure-7

Inter-annual variation and linear trend analysis on the Satellite derived SST data

17. Annual mean temperature has an increasing trend at all stations. It is revealed by Table-1 that the annual mean SST in the offshore waters of Pakistan has registered an increasing trend about  $0.2^{\circ}\text{C}$  per decade. Analysis of satellite derived SST data from 1985 to 1999 shows increment rate at Karachi about  $0.3^{\circ}\text{C}$  per decade (Khan, 2004).

Table-1

Table 1. Annual linear trend in °C/decade performed on the SST time-series			
S. No.	Station	Latitude & Longitude	Annual Linear trend in °C/decade
1.	Keti Bandar	24° 05.00 N 67° 10.00 E	0.20
2.	Karachi	24° 37.38' N 66° 54.42' E	0.28
3.	Sonmiani	25° 22.27' N 66° 32.19' E	0.21
4.	Gwadar	24° 56.42' N 62° 20.27' E	0.21
5.	Ormara	25° 07.39 N 64° 66.77 E	0.20

18. The interesting feature of SST trends along Pakistan coast is the rising rate, which shows that Global warming impact does not vary much from one location to another.

**Historic Data Record and Sea Level Variations**

19. Inter-annual variation of monthly mean sea level and the 5-month running average at Karachi is indicated in Figure-8. The average seasonal cycle and linear sea level trend have been removed. Inter-annual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The frequent discontinuation of monitoring of tidal data at Karachi port was mainly due to siltation of tide gauge site and non-ops status of the gauge. The gauge location has been shifted now to OP-I/II in the harbour.

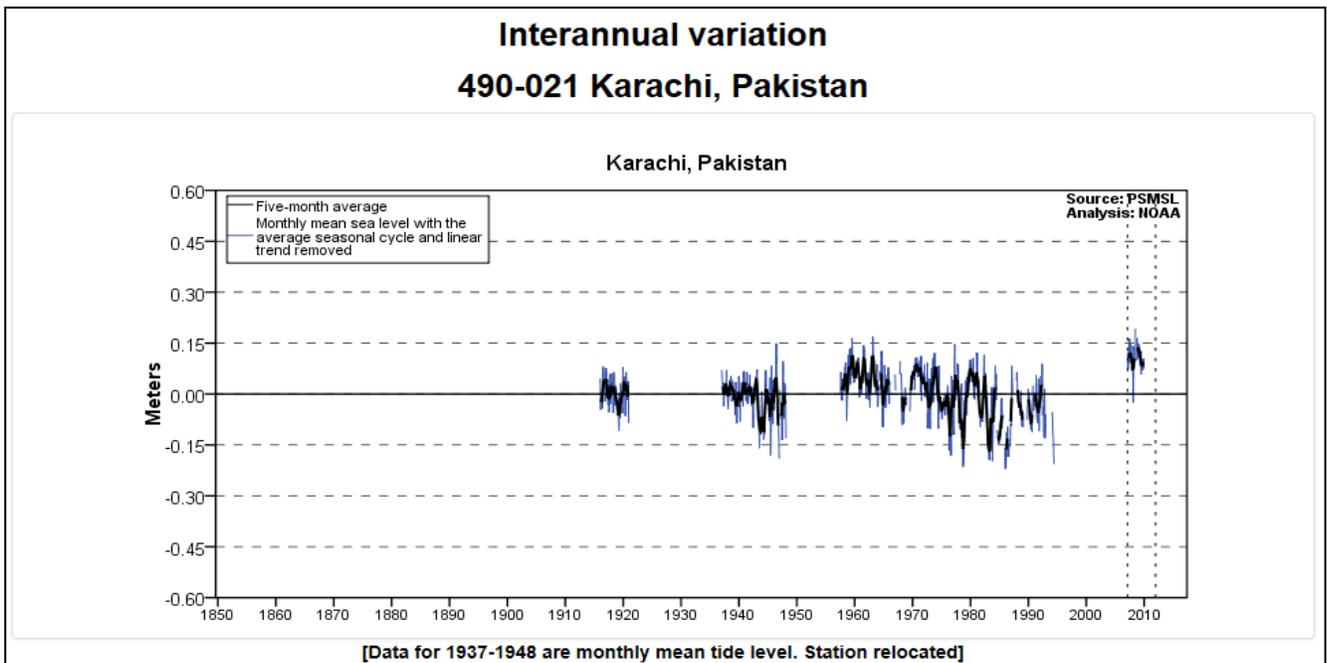


Figure-8  
Inter-annual variation of mean sea level (1916 – 2010)

20. The average seasonal cycle of mean sea level, caused by regular fluctuations in coastal temperatures, salinities, winds, atmospheric pressures, and ocean currents, is shown along with each month's 95% confidence interval is highlighted in Figure-9.

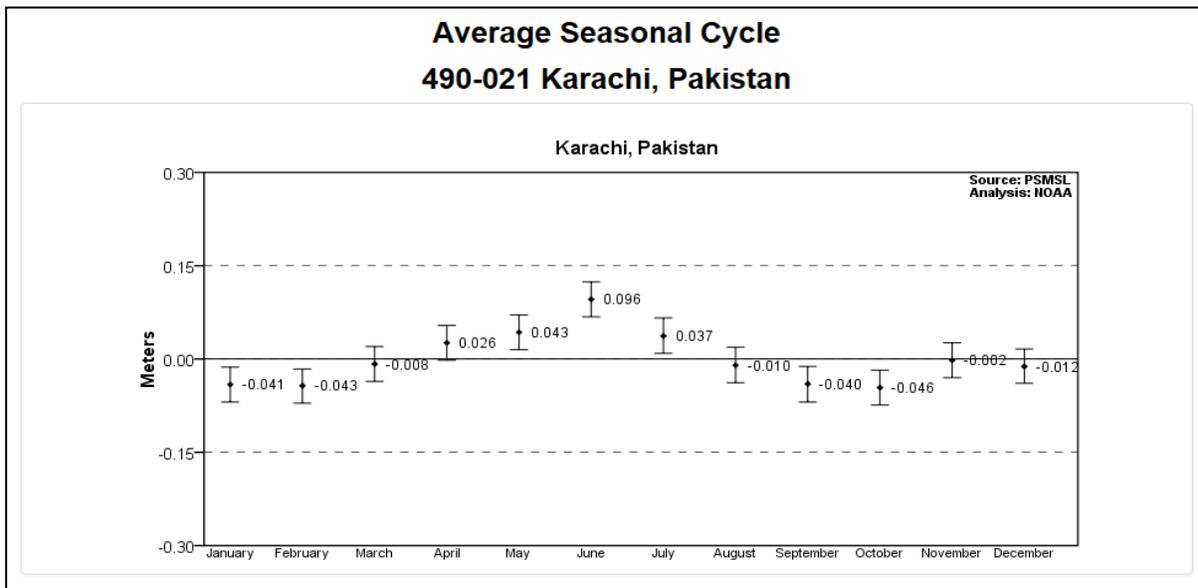


Figure-9

21. Monthly mean sea level without regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents is indicated in Figure-10. The long-term linear trend is also shown, including its 95% confidence interval. The plotted values are relative to the most recent Mean Sea Level datum established by Center for Operational Oceanographic Products and Services (CO-OPS).

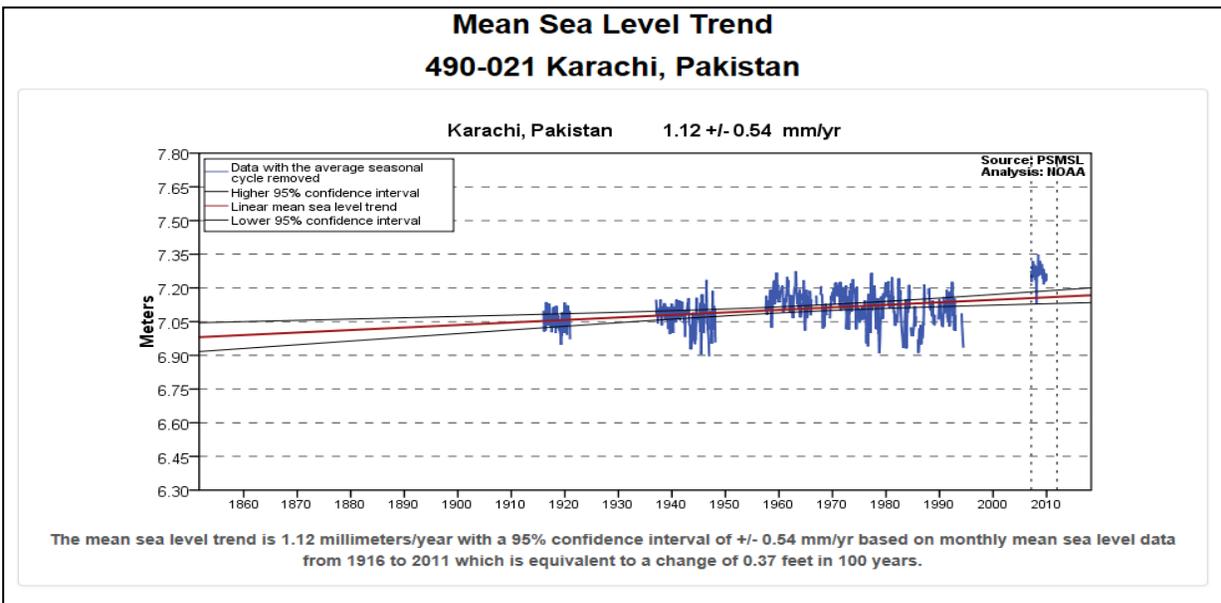


Figure-10

## TIDE GAUGES NETWORK ALONG THE COAST

22. Monitoring of tidal data along the Pakistan coast through GLOSS designated tide gauges in the past remained intermittent mainly due to miscellaneous reasons. However, with the replacement of tide gauge stations, it is likely that continuous and un-interrupted data would remain available in future. Presently, tide gauges are installed permanently at following locations:

- a. Karachi Ops
- b. Ormara Ops (firm upgradation required)
- c. Gwadar Ops (firm ungradation required)
- d. Creek Areas - (installation planned in 2013-14)

23. Although, installed tide gauges along the coast (Ormara and Gwadar) are technically operational; however, firm upgradation is required for available of meaningful dataset. Coordination for the same is presently in progress.

24. Details of GLOSS tide gauge installed at Karachi with IOC/ UNESCO funding programme is shown in Figure-11. The gauge is part of tsunami early warning system. The graph in the figure indicates 7 days tidal curve recorded at Karachi in mid Oct 13. Similar tide gauges are installed at Ormara and Gwadar also.

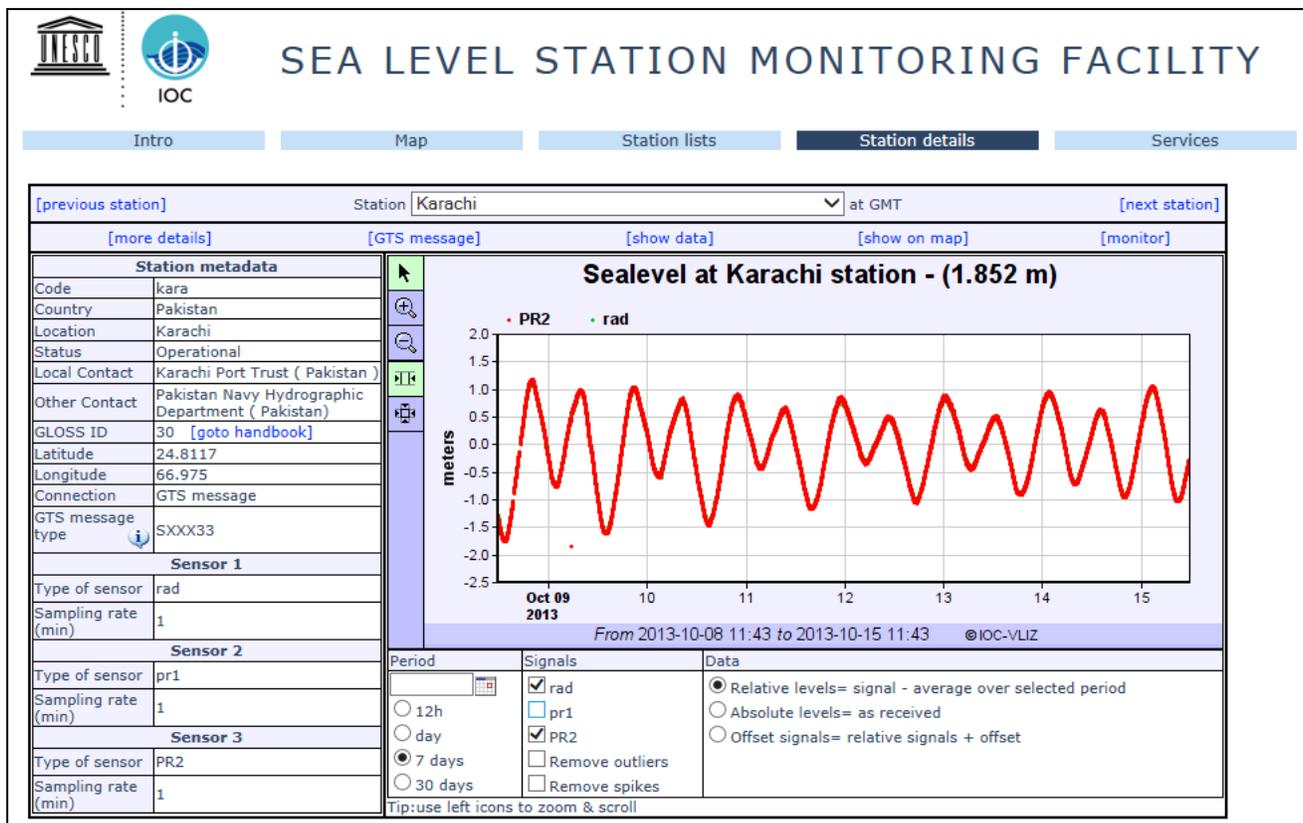


Figure-11

## **SUBDUCTION ZONE ALONG MAKRAN COAST AND EMERGENCE OF ISLETS**

25. Makran coastal belt lies over a subduction zone. As a result of any tectonic activity in the area, usually Islets emerge in the offshore area (Arabian Sea). Repeated events of islets emergence have been recorded in the past. Latest being in Sep 13, when 4 islets emerged suddenly as a result of an earthquake in Pakistan. In November 1945, a Tsunami was generated off the Makran coast due to a large earthquake which caused loss to human lives in addition to formation of small islets in this area. Again in March 1999 and November 2010, similar Islets emerged near Ras Malan area along Makran coast which later eroded due wave action. Reason for the emergence of offshore Islet is the escape of highly pressurized gas hydrates from weak crustal place. Whenever seismic activity happens, it creates escape routes and gas hydrates trapped in mud, follow these routes and this process causes emergence of such Islets.

## **INCREASED FREQUENCY OF CYCLONES IN ARABIAN SEA**

26. Due to flat topography, Sindh coastal zone is more vulnerable to sea level rise than Baluchistan coast, as uplifting of the coast by about 1-2 mm/year due to subduction of Indian Ocean plate is a characteristic of Baluchistan coast.

27. Indus deltaic creek system (Sindh coast) is prone to storm/ cyclones, which cause great deal of inundation in the low lying areas. The Arabian Sea's average temperature has gone up during the last 40 years. This has given rise to some major cyclones which were never spotted in the Arabian Sea. During the end of 20<sup>th</sup> century and beginning of 21<sup>st</sup> century, three major category cyclones formed in the Arabian Sea. In June 1998, a cyclone with winds up to 120 mph smashed Indian State of Gujarat killing 10,000 people. In May 1999, a powerful cyclone (A2) with winds up to 125 mph battered Sindh province of Pakistan, killing 6400 people. The incident was a catastrophe for the people of the area. Hectors of agriculture land was flooded with saline water. The storm was just 100 km away from Karachi. In May 2001, a cyclone with winds up to 125 mph made landfall near Gujarat, killing 900 people.

28. Evidence suggests that cyclones have in fact increased between 1979 and 2011, both in frequency and strength. The area has seen some strong tropical activity in the Arabian Sea in recent years that are 2001, 2004, 2007, 2010 and 2011.

## **POTENTIAL ANOMALIES AND MISCELLANEOUS FACTORS**

29. Amongst major causes of global sea level changes, factors such as meteorological, hydrological, volcanic and tectonic usually prevent accurate estimates of sea level variations (Pirazzoli, 1993). Local land subsides/ uplift and tectonics could significantly increase or decrease the apparent SLR. Necessary corrective measures are required for better monitoring of sea level variations.

## **IMPORTANT ASPECTS OF OFFSHORE REGION**

30. Geographic location of Pakistan and associated offshore region merits special considerations for sea level monitoring aspects. Based on above mentioned discussions, following are important aspects:

- a. Variation of sea level and rise in temperature.
- b. Increase in SST along the coast.
- c. Tectonic aspects for which uplifting/ subduction phenomenon is common.
- d. Non-existence of tectonic plate monitoring mechanism.
- d. Regular emergence of islets along the coast which disturbs seabed.
- e. Non availability of weather monitoring system in the offshore region.
- f. Increase in cyclonic activities in the area.

## **WAY FORWARD**

31. In order to address proper monitoring mechanism of sea level along the Pakistan coast, there is a need to establish a comprehensive vertical control (Vertical Off shore Reference Frame) through integrating all possible variables in order to assess absolute movements and variations. IOC/ UNESCO may assign special consideration and may treat the coast of Pakistan as a special case for monitoring/ correlating all above mentioned variables. Special funding for placement of a comprehensive mechanism may be considered. Initially, following is required on priority:

- a. Monitoring of plate tectonic activities like uplift, subduction through GPS technology is proposed in the coastal region. Owing to the geographical location and Pakistan coast being at the margin of subduction zone, monitoring such activities has important linkage with sea level variations.
- b. Additional tide gauges (about 6) are required to be included in the network of available tide gauges along the coast. A network of seabed tide gauges is also considered essential for relative monitoring of vertical water column in the offshore region. Furthermore, dataset of tide gauges are required to be monitored at local level through available technology.
- c. Additional sensors like Automatic Weather Stations and weather radars are required for maintaining database for meteorological parameters (SST, wave/ swell height, current pattern etc). At present, adequate meteorological information in the coastal region is not available due to non-availability of data logging network. In addition, such information is also not available in the offshore areas.

## **BENEFITS TO INTERNATIONAL COMMUNITY**

32. Installation of setup proposed at para 31 along Pakistan coast will make possible to provide research quality data continuously to PSMSL under GLOSS programme. The GLOSS is an international programme coordinated by the IOC for the establishment of high

quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. Therefore IOC-UNESCO must allocate funds for the proposed setup to ensure the continuous recoding of sea level variations along Pakistan coast and smooth flow of collected data to PSMSL/GLOSS data bank.

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